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RESEARCH MEMORANDUM

INVESTIGATION OF PRESSURE LOSSES IN SEVERAL TURBOSUPERCHARGER NOZZLE BOXES

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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INVESTIGATION OF PRESSURE LOSSES IN SEVERAL TURBOSUPERCHARGER NOZZLE BOXES

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SUMMARY

Surveys were made of the impact pressure of the flow to obtain information for determining pressure losses in the following turbo-supercharger nozzle boxes:

A, scroll nozzle box with bent sheet-metal vanes
B, scroll nozzle box with airfoil-shape vanes
C, scroll nozzle box with airfoil-shape vanes and a dam
D, symmetrical nozzle box with airfoil-shape vanes

The surveys covered the entire nozzle annulus and were made at several inlet pressures ranging from 10 to 40 inches of mercury above atmospheric. The data indicated substantial differences in total head loss among the boxes and the existence of sharply defined high-loss regions in portions of the nozzle annulus. Scroll nozzle box A with bent sheet-metal vanes had the highest over-all total-head losses; symmetrical nozzle box D with airfoil-shape vanes, at an inlet total pressure of 30 inches of mercury gage, had losses 6 percent lower than nozzle box A and at the same inlet pressure scroll nozzle boxes B and C having airfoil-shape vanes, and with or without a dam, respectively, had losses 30 percent lower than nozzle box A.

INTRODUCTION

Improvements in the efficiency of the turbine of conventional turbosuperchargers have not received much attention because the power available in the exhaust gas of an aircraft engine is more than that required for supercharging. Instead, emphasis has been justifiably placed on light weight and ease of manufacture. The current interest in composite-engine operation in which the energy in the exhaust gas of the reciprocating engine is more completely utilized by gearing these turbines to the crankshaft of the engine, has emphasized the importance of high turbine efficiency.

As part of an investigation to improve the efficiency of the turbine of the turbosupercharger, research is being conducted at the

NACA Cleveland laboratory to determine the losses in conventional turbosupercharger units. In order to determine the pressure losses in several nozzle boxes, total-pressure surveys of the flow from the nozzle annulus of four turbosupercharger turbine-nozzle boxes were made at atmospheric discharge pressure for a range of total inlet pressures from 10 to 40 inches of mercury above atmospheric and the results obtained are reported.

APPARATUS AND METHOD

Pertinent dimensions and other characteristics of the nozzle boxes investigated are listed in the following table:

Designation	Shape	Type of vane	Number of vanes	Nozzle area (sq in.)	Nozzle-discharge angle (deg)	Cone angle (deg)	Pitch diameter (in.)	Waste gate
A	Scroll	Bent sheet metal	38	10.8	22	0	11.0	Blanked
B	Scroll	Cast air-foil	46	10.3	20 - 22	15	11.0	Blanked
C	Scroll with dam	Cast air-foil	46	10.3	20 - 22	15	11.0	Blanked
D	Symmetrical	Cast air-foil	44	17.8	24	15	13.2	None

Outlines of the scroll and symmetrical nozzle boxes are shown in figure 1. The position of a sheet-metal dam installed in scroll nozzle box C to prevent the entering stream from separating into each of the passages is also shown. Dimensioned details of the nozzles, nozzle angles, and cone angles are given in figure 2. The stream leaving the nozzles rotates in a counterclockwise direction looking upstream. Shroud rings, consisting of hoops made of $\frac{1}{8}$- by 1-inch strips, were fastened to the outer diaphragm rings to prevent the stream leaving the nozzles from mushrooming in the region of the survey. No effort was made to improve the manufacturer's surface finish on the nozzle vanes.

The setup of the equipment is shown in figure 3. The nozzle-box inlet was connected to the laboratory air system, which supplied air at room temperature. An automatic pressure regulator was installed in the inlet pipe to maintain the desired total pressure at the nozzle-box entrance. The locations of the impact tube for measuring the nozzle-box inlet total pressure and the thermocouple for measuring the inlet total temperature are shown in figure 3.

The survey apparatus for measuring the total pressure at the nozzle exits consisted of a total-head tube, synchronous motor drive, and a clock-driven continuous pressure recorder. Several types of total-head tube were tried before one was found that was sufficiently small to cause only a small disturbance in the nozzle jet and still rigid enough to remain undeflected by the air stream. The tube that was found to be satisfactory and was used in this investigation is shown in figure 4.

The survey tube was mounted on a rotating arm with the faired end pointed upstream parallel to the nozzle jet. The distance from the nozzle face to the tube inlet was set at 0.1 inch, which is approximately the location of the leading edge of the buckets in an operating turbine. The radius of the survey arm could be changed to cover the entire annulus. The tube and arm are shown in figure 5. The rotating arm was mounted on the turbine shaft where the wheel is ordinarily fastened. A synchronous motor drove the shaft through reduction gears at approximately 1/15 rpm. At this speed, the pressure fluctuations that the tube experiences as it travels across each of the nozzle vanes could be accurately recorded.

The pressure recorder was a commercial instrument, which consisted of a moving chart and a pen swung about a pivot by a Bourdon tube to give nearly linear displacement with pressure. The accuracy of the recorder was $\pm 1\frac{1}{2}$ percent of full scale.

Determinations were made with nozzle-box-inlet pressures of 10, 20, 30, and 40 inches of mercury above atmospheric and with atmospheric discharge pressure. Circumferential pressure surveys were made at radii that differed by increments of 0.125 inch. The first and last surveys were made 0.020 inch from the inner and outer edges of the nozzle annulus, respectively.

RESULTS AND DISCUSSION

A recording of the discharge total pressure made along the pitch-line circumference of nozzle box A at a distance of 0.1-inch from the annulus face and with a nozzle-box inlet total pressure of 30 inches of mercury gage is shown in figure 6. The vertical scale is in pounds per square inch gage and the circular arcs show the path of the pen about its pivot. The pressure cycles are numbered according to the numbers assigned to the corresponding nozzles in subsequent figures and discussion. The position of each of the nozzle vanes is obvious from the dips in the curve. The dashed line representing the inlet total gage pressure is a measure of the available head. The vertical distance from the survey curve to the inlet total-pressure line is equal to the instantaneous loss in total head from the nozzle-box inlet to the plane corresponding to the bucket inlet.

The mean total-head loss of each nozzle at the pitch diameter was determined by dividing the area under that portion of the discharge total-pressure curve corresponding to the pitch of the nozzle by the projected length of the curve and subtracting from the available head. Mean total-head loss of each of the nozzles at the pitch line for each nozzle box and for several inlet pressures is shown in figure 7. A sketch of each nozzle box is reproduced to show the relation of the nozzle numbers to the position in the box. The direction of discharge from the nozzle box is, in each case, counterclockwise.

Examination of figure 7 shows that scroll nozzle boxes A and B and symmetrical box D each have a well-defined portion of the annulus in which head losses are high and suggests that the air streams in the two passages join and form eddies in this region. The region of high losses in scroll nozzle box A is in the left branch where the angle of attack of the flow on the vanes is high. The highest losses in scroll nozzle box B with airfoil-shape vanes occur at nozzles 30 and 31 and those in symmetrical nozzle box D are centered approximately at nozzle 21 in the right branch. The mean total-head losses of the scroll nozzle boxes increase progressively along the length of the scroll passage with attendant decrease in passage area up to the region of high loss. The use of airfoil-shape (nozzle box B) instead of bent sheet-metal vanes (nozzle box A) reduces this effect and the installation of the dam (nozzle box C) almost eliminates it. When the inlet total pressure was increased, the locations of the regions of high losses did not change. No correction was made for the reduction in the recovery factor of the survey tube at the supercritical pressure ratios.

The mean total-head loss over the entire circumference at each surveyed radius of the nozzle annulus was obtained by dividing the area under the entire discharge total-pressure curve (similar to fig. 6) by the projected length of the trace and subtracting from the available head. These loss curves are shown in figure 8 for several inlet pressures. The curves indicate substantial losses at inner and outer annulus walls. Scroll nozzle box A with bent sheet-metal vanes has a minimum head loss at a radial position approximately three-fourths of the distance from the inner to the outer ring. The same nozzle box with airfoil-shape vanes (nozzle box B) has considerably flatter loss curves, which are also lower in magnitude. The installation of the dam in the box with airfoil-shape vanes (nozzle box C, fig. 8(c)), however, produces mean total-head-loss curves similar to those of the nozzle box with bent sheet-metal vanes (nozzle box A) but the magnitude of the losses is similar to those of nozzle box B. The mean total-head-loss curves obtained with symmetrical nozzle box D show waves and indicate minimum head losses near the inner diaphragm. When the nozzle-box inlet total pressure is increased, the losses increase but do not change the profiles of the mean total-head-loss curves.

The over-all mean total-head loss of a nozzle box was obtained by dividing the area under the mean total-head-loss curves of figure 8 by the annulus height and is plotted in figure 9 against nozzle-box inlet total pressure for the four nozzle boxes. The over-all mean total-head losses vary approximately linearly with inlet pressure. Scroll nozzle box A with bent sheet-metal vanes has the highest losses; symmetrical nozzle box D with airfoil-shape vanes at an inlet total pressure of 30 inches of mercury gage has losses 6 percent lower than nozzle box A; and at the same inlet pressure, scroll nozzle boxes B and C having airfoil-shape vanes and with or without the dam, respectively, have losses approximately 30 percent lower than nozzle box A. Although the effect of the dam on the over-all total-head loss of the nozzle box is slight, the more uniform circumferential total-head profile may be expected to result in a higher turbine efficiency because the jet from such a nozzle box can be more efficiently utilized by a turbine wheel.

SUMMARY OF RESULTS

The results of discharge total-pressure surveys of four nozzle boxes with various inlet total pressures show that:

1. Scroll nozzle box A with bent sheet-metal vanes, B with airfoil-shape vanes, and symmetrical nozzle box D with airfoil-shape

vanes had a well-defined portion of the annulus in which the mean total-head loss of each nozzle was high.

2. Scroll nozzle box C with airfoil-shape vanes and a dam produced an almost uniform circumferential mean total-head loss distribution.

3. Scroll nozzle box A with bent sheet-metal vanes had the highest over-all total-head losses; symmetrical nozzle box D with airfoil vanes at an inlet-total pressure of 30 inches of mercury gage had losses 6 percent lower than nozzle box A and at the same inlet pressure the scroll nozzle boxes B and C, having airfoil-shape vanes and with or without the dam, respectively, had losses approximately 30 percent lower than nozzle box A.

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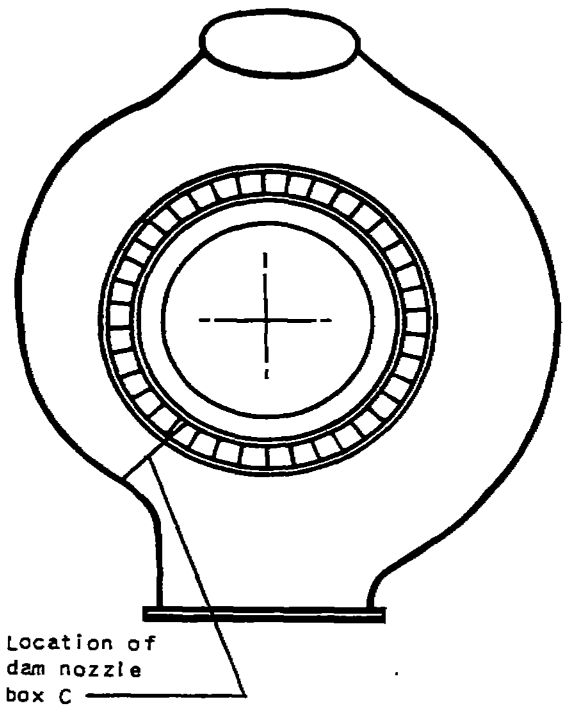
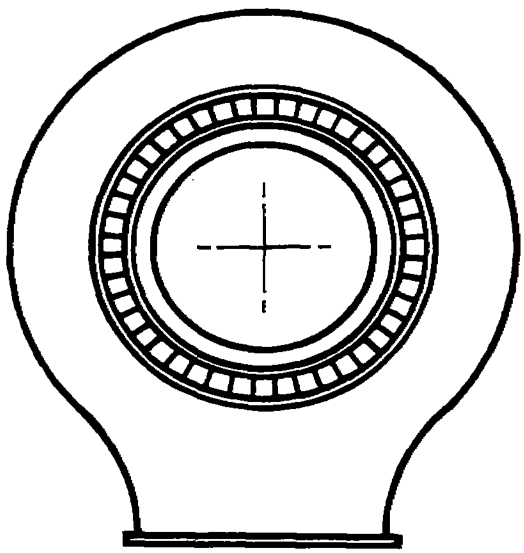


(a) Scroll nozzle boxes
A, B, and C.



(b) Symmetrical nozzle box D.

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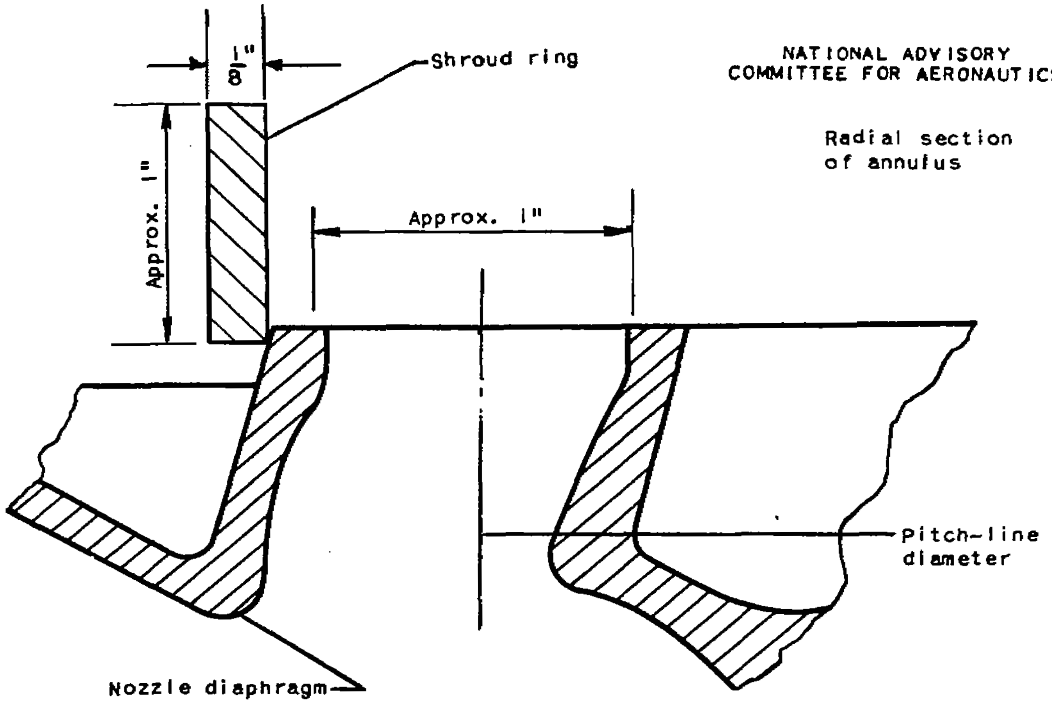
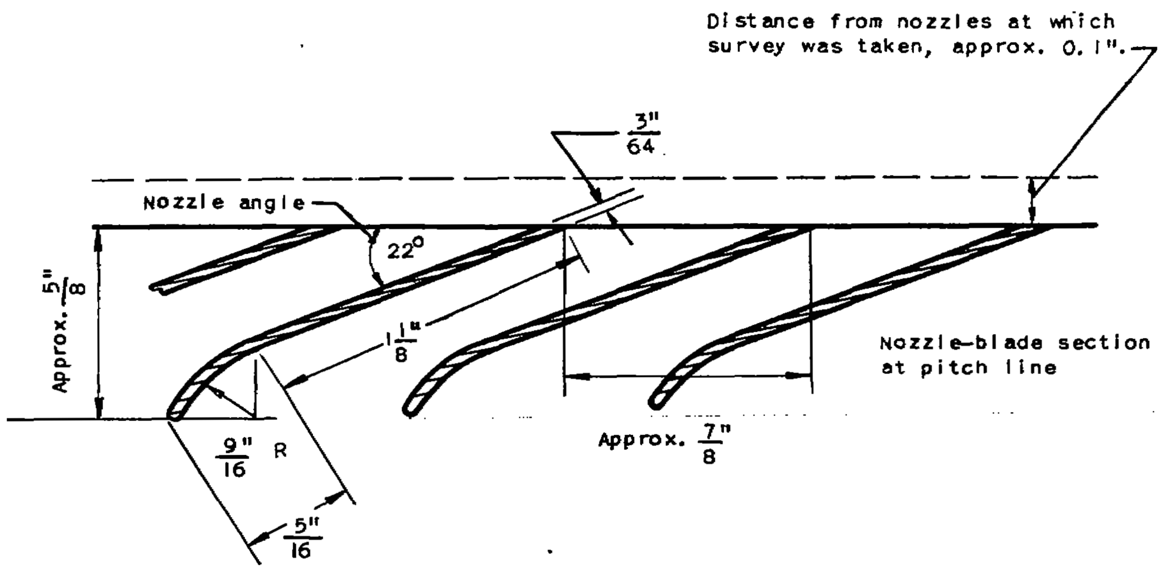
Figure 1. - Outlines of nozzle boxes.





(a) Scroll nozzle box A with bent sheet-metal vanes.

Figure 2. - Nozzle-blade and annulus sections.

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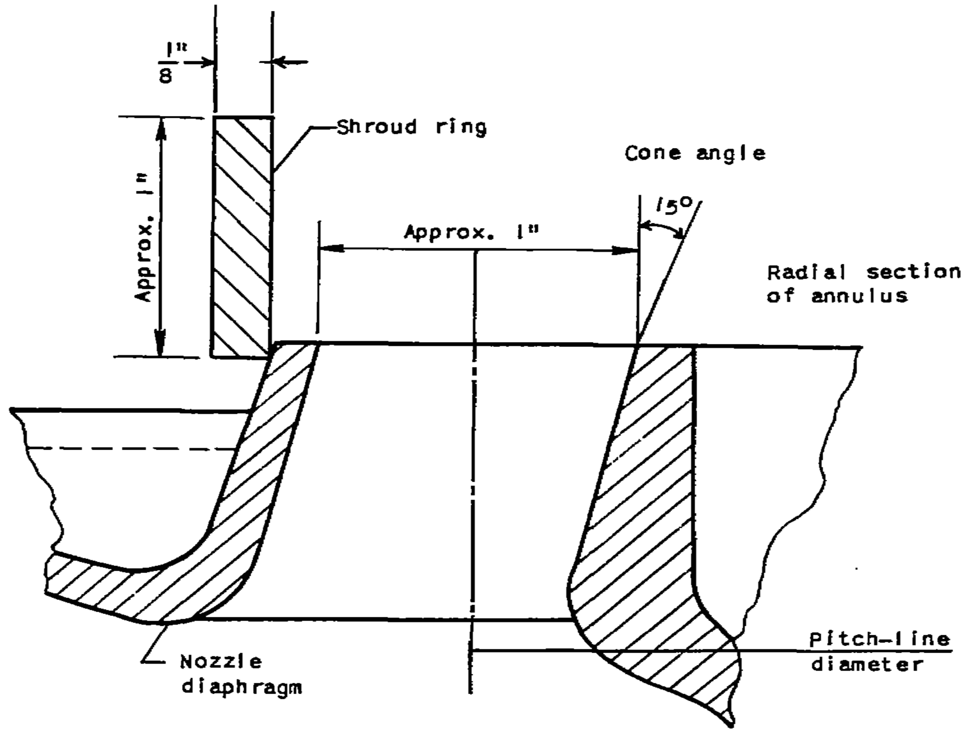

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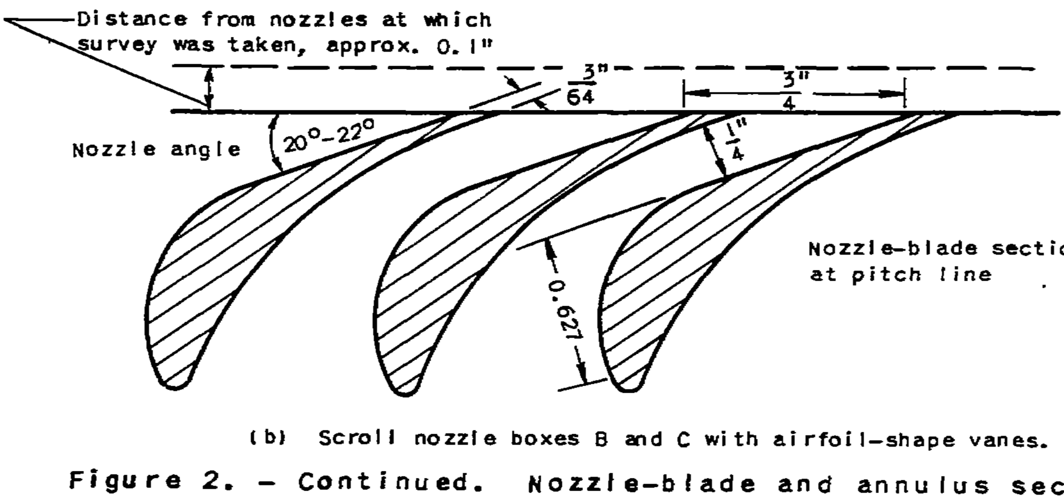
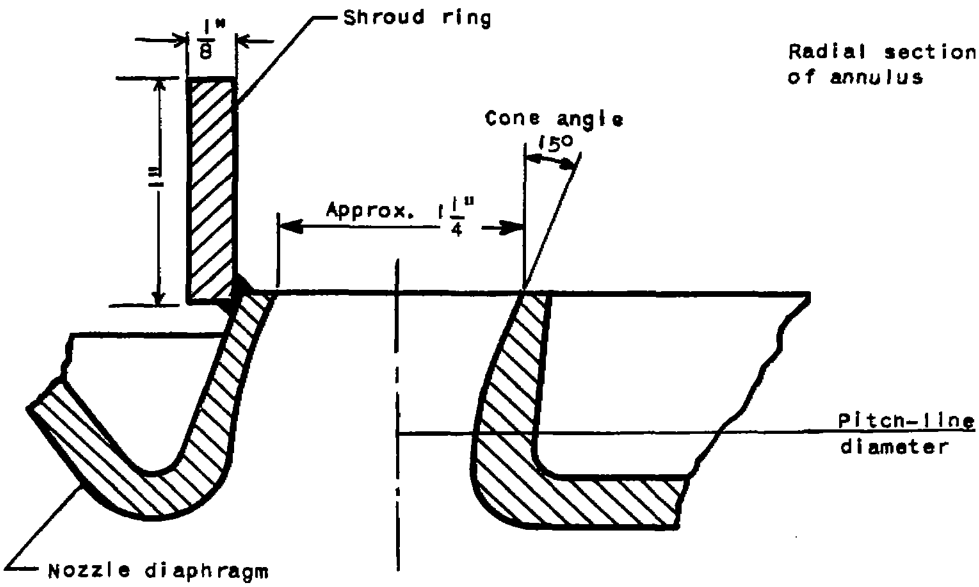


(b) Scroll nozzle boxes B and C with airfoil-shape vanes.

Figure 2. - Continued. Nozzle-blade and annulus sections.



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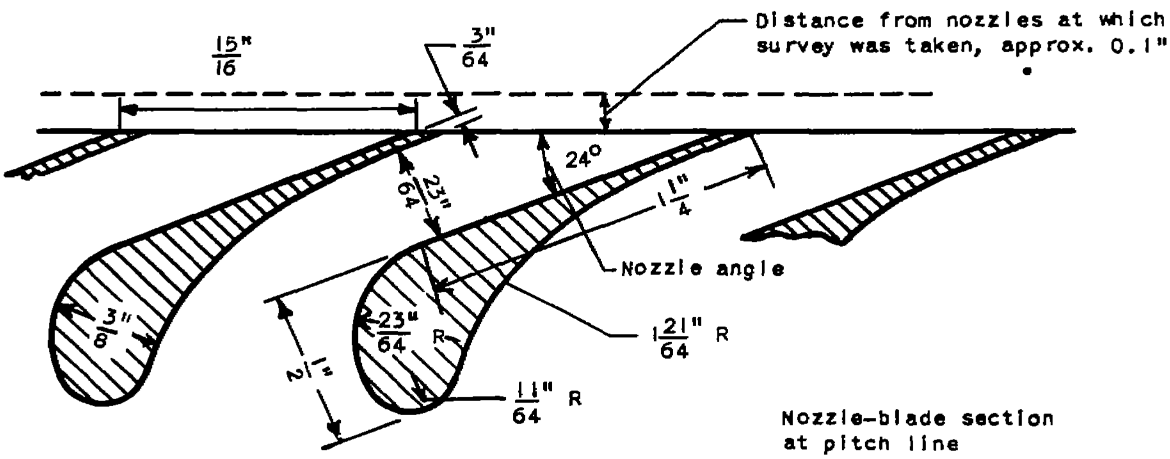

(c) Symmetrical nozzle box D with airfoil-shape vanes.

Figure 2. - Concluded. Nozzle-blade and annulus sections.

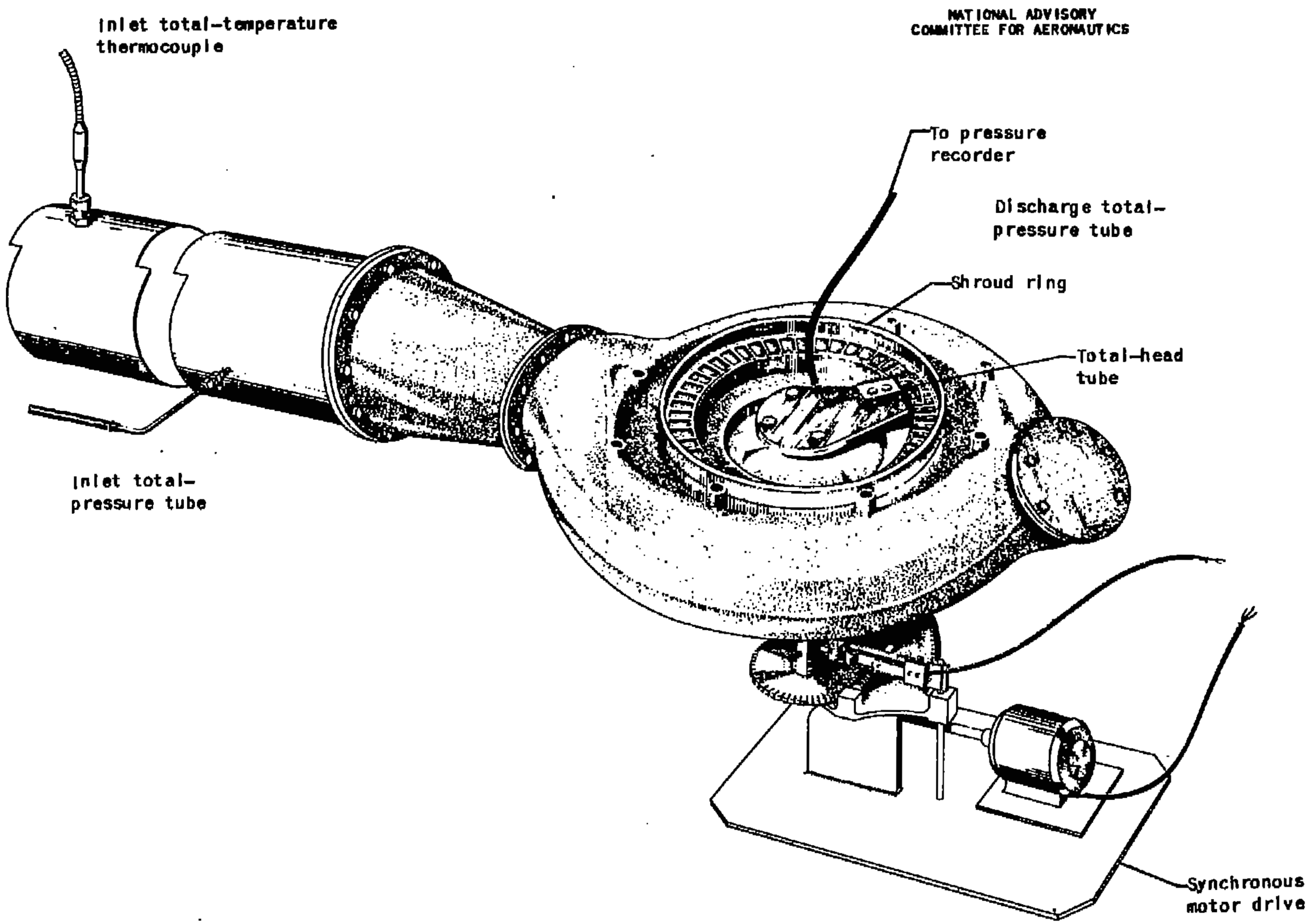

Figure 3. - Nozzle-box and survey-tube drive apparatus.

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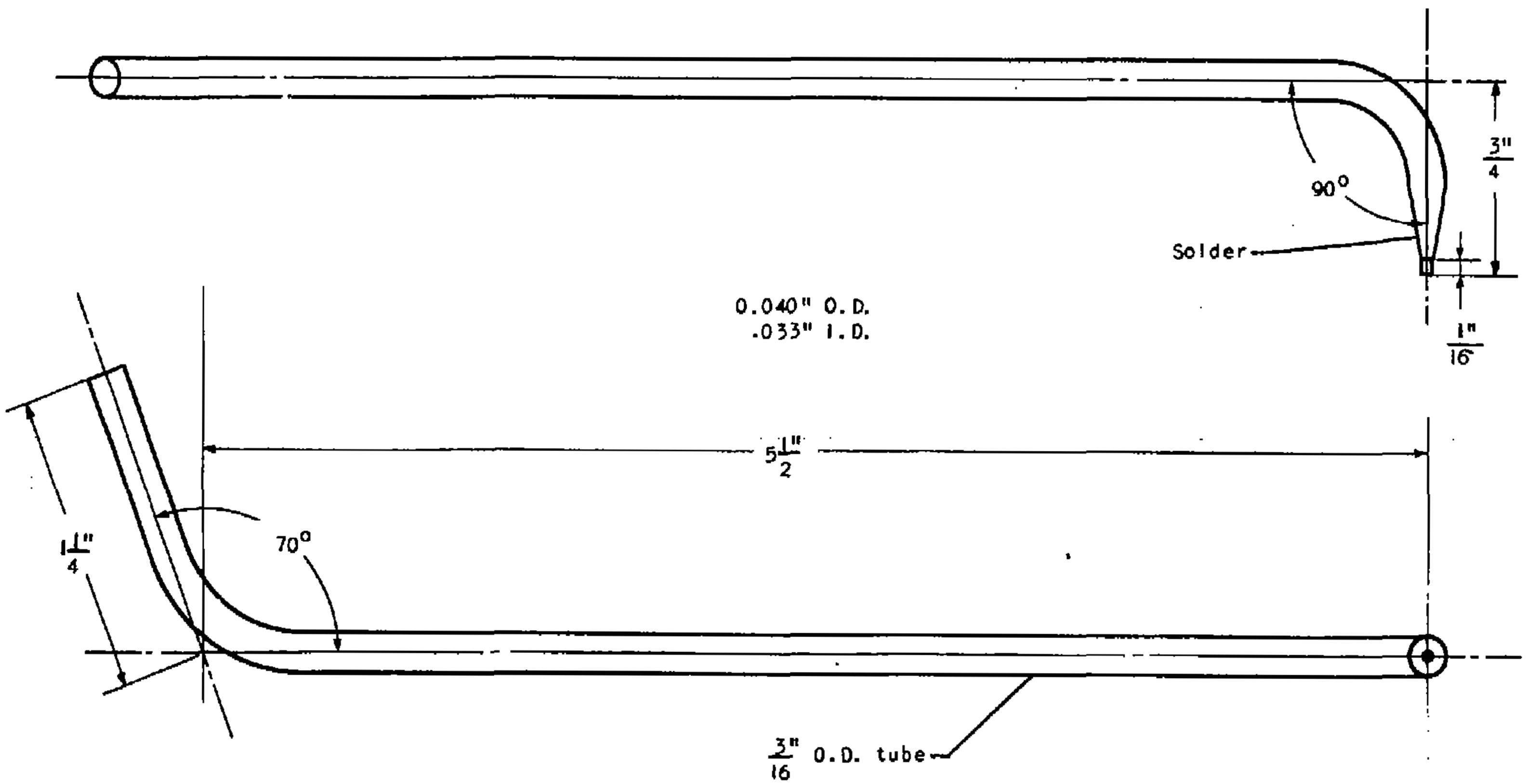

Figure 4. - Discharge total-head survey tube.

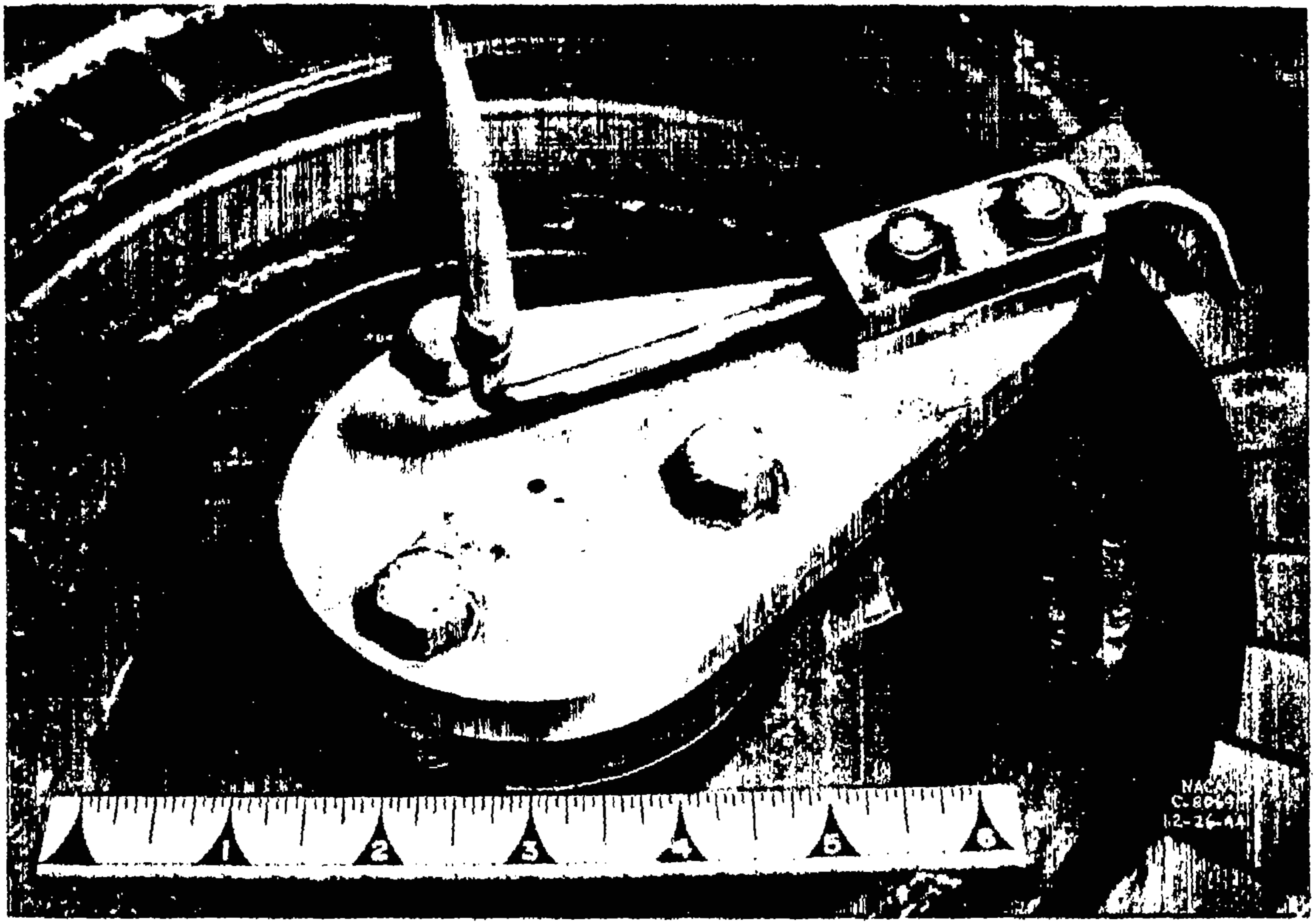

Figure 5. - Discharge total-head tube mounted on nozzle box A.

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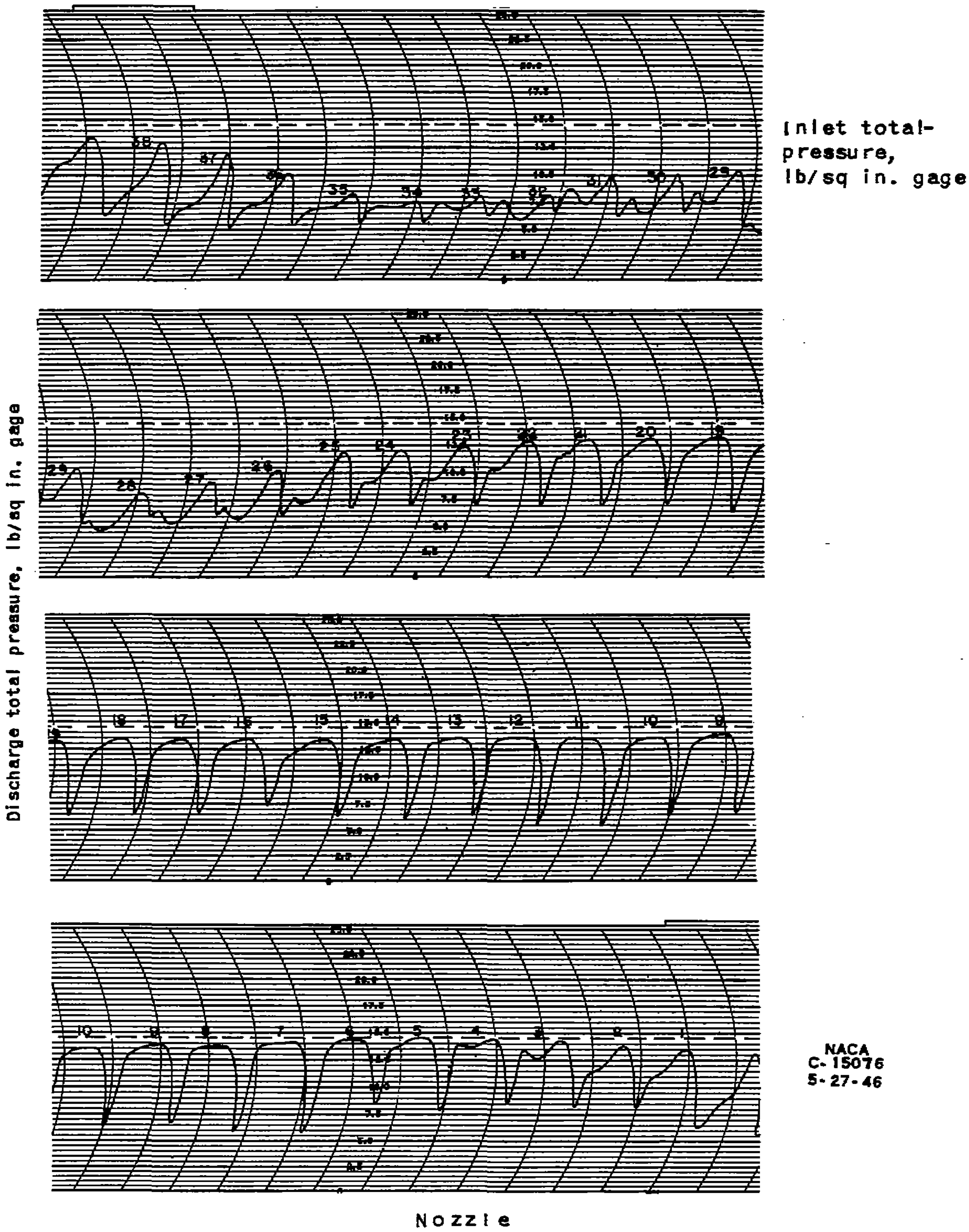
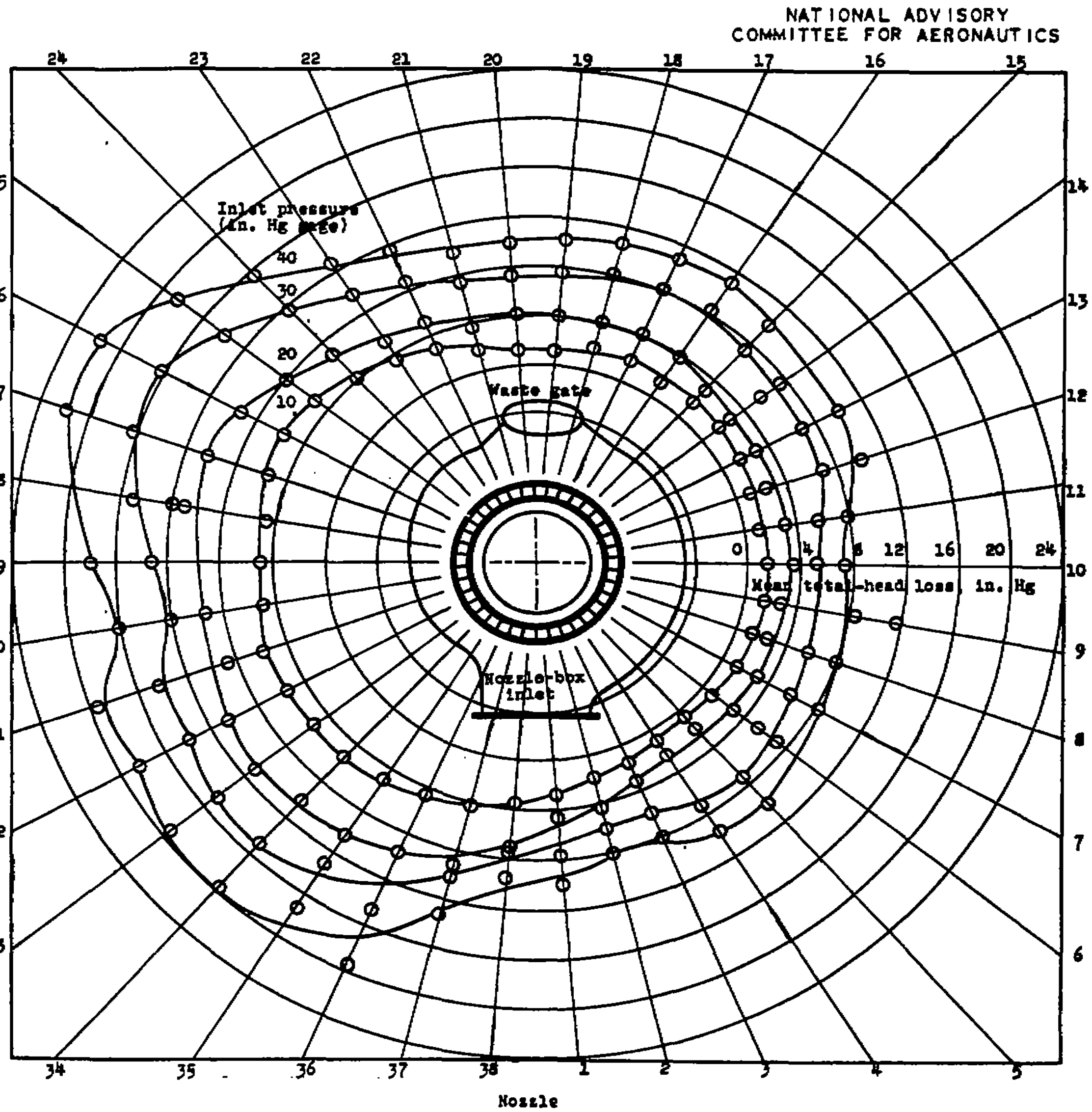


Figure 6. - Discharge total-pressure recording taken at inlet total pressure of 30 inches of mercury gage, Nozzle box A.



(a) Nozzle box A.

Figure 7. - Mean total-head loss of each nozzle at pitch line.

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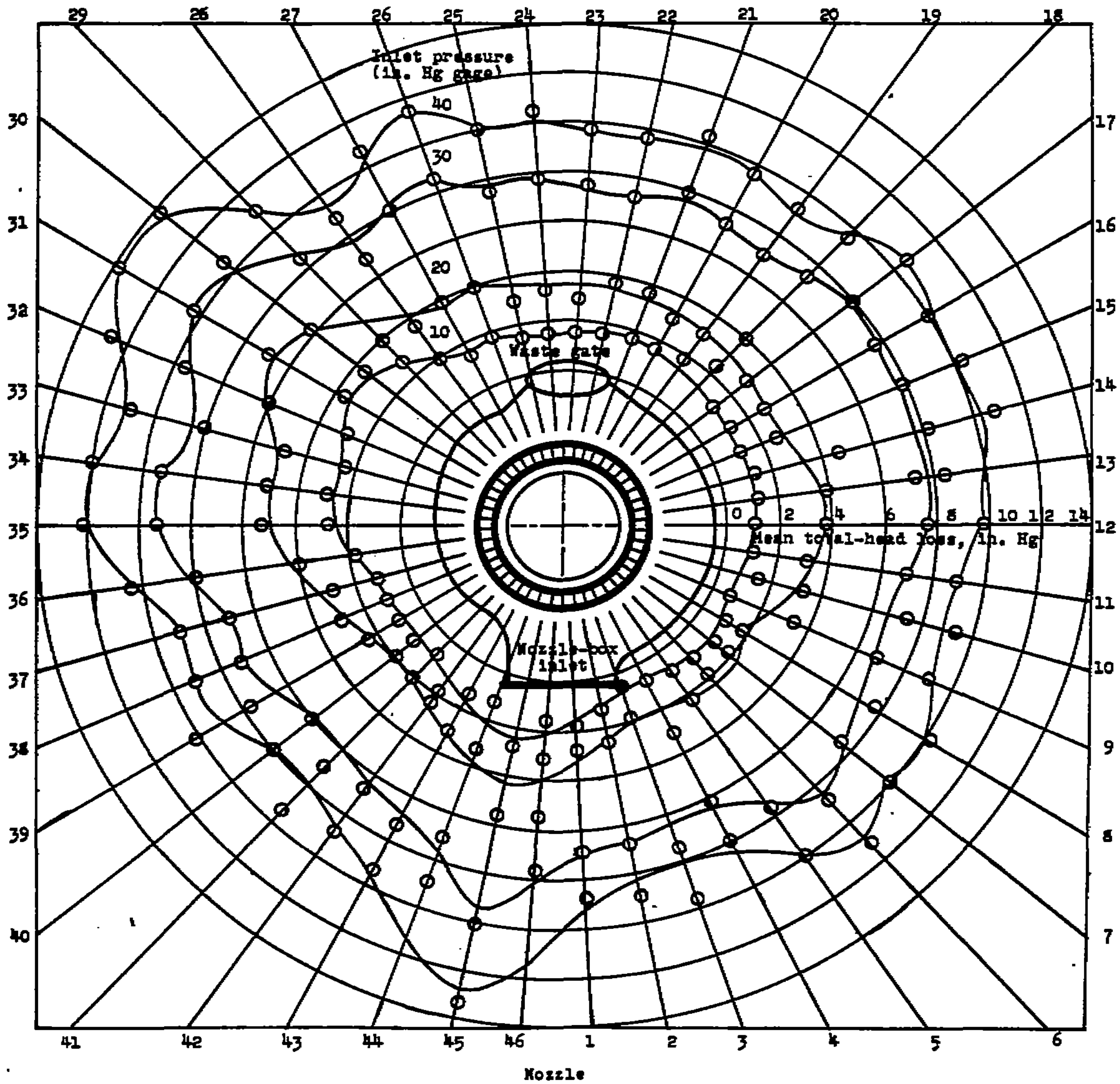
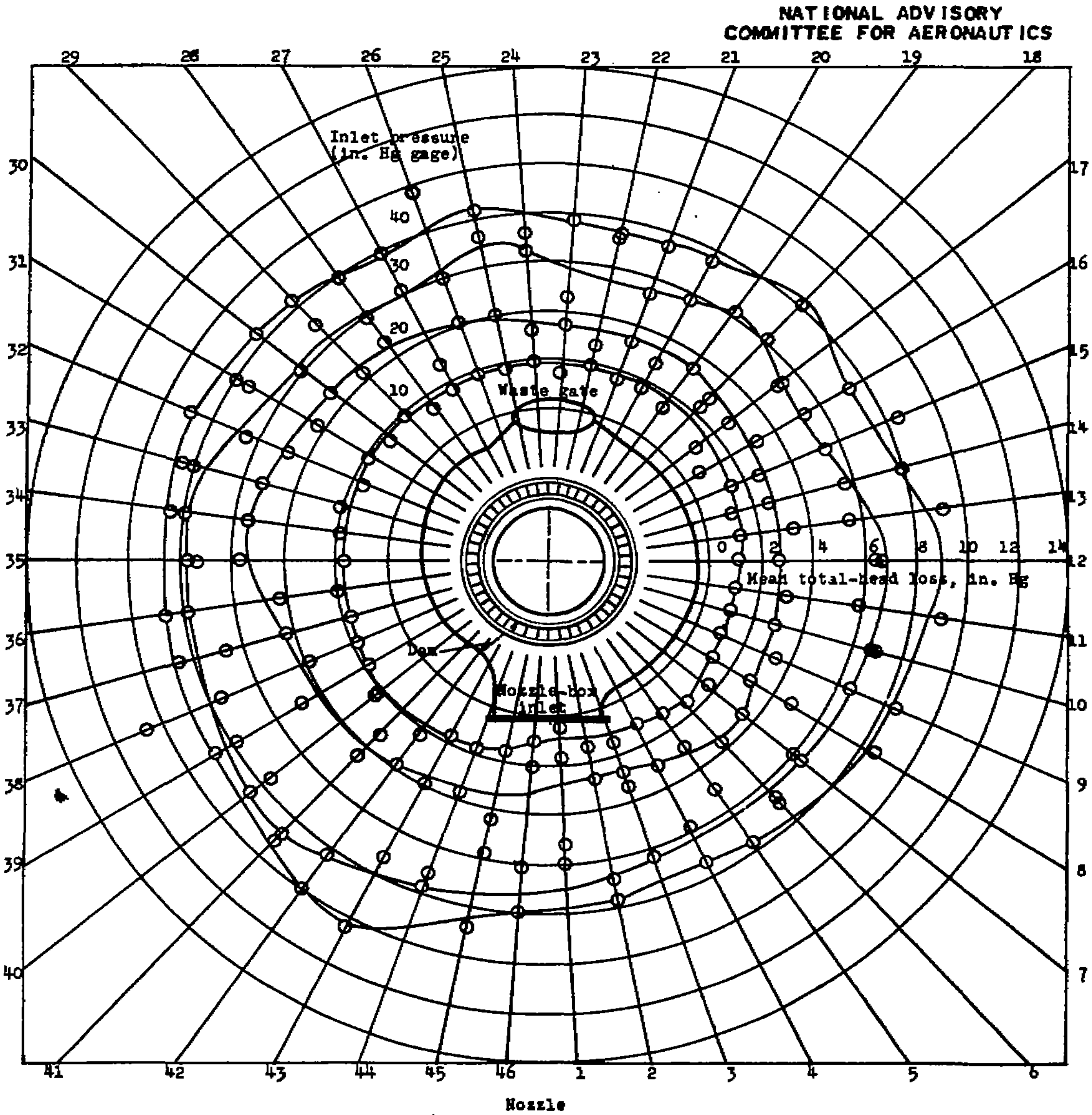


(b) Nozzle box B.

Figure 7. - Continued. Mean total-head loss of each nozzle at pitch line.



(c) Nozzle box C.

Figure 7. - Continued. Mean total-head loss of each nozzle at pitch line.

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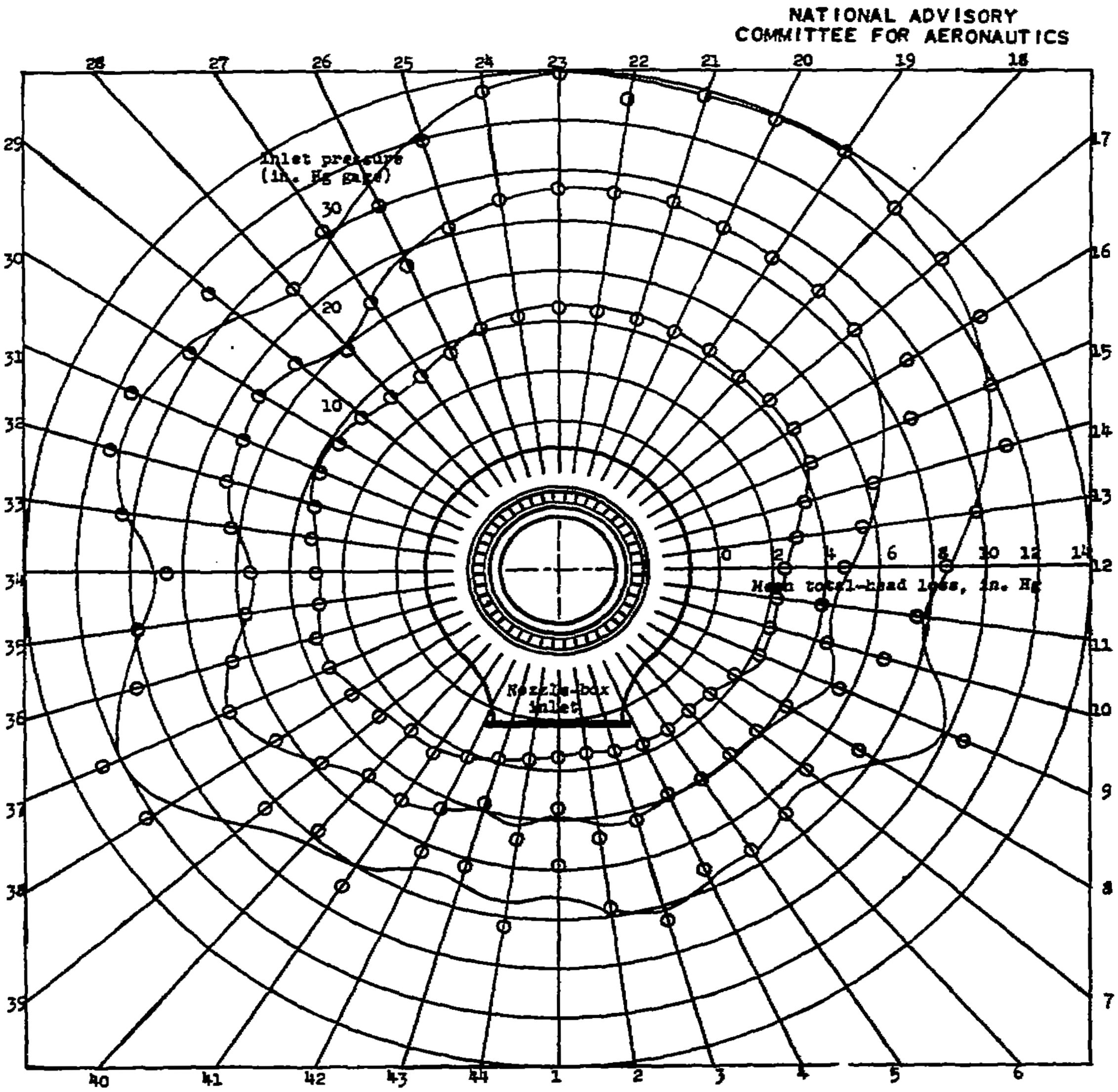
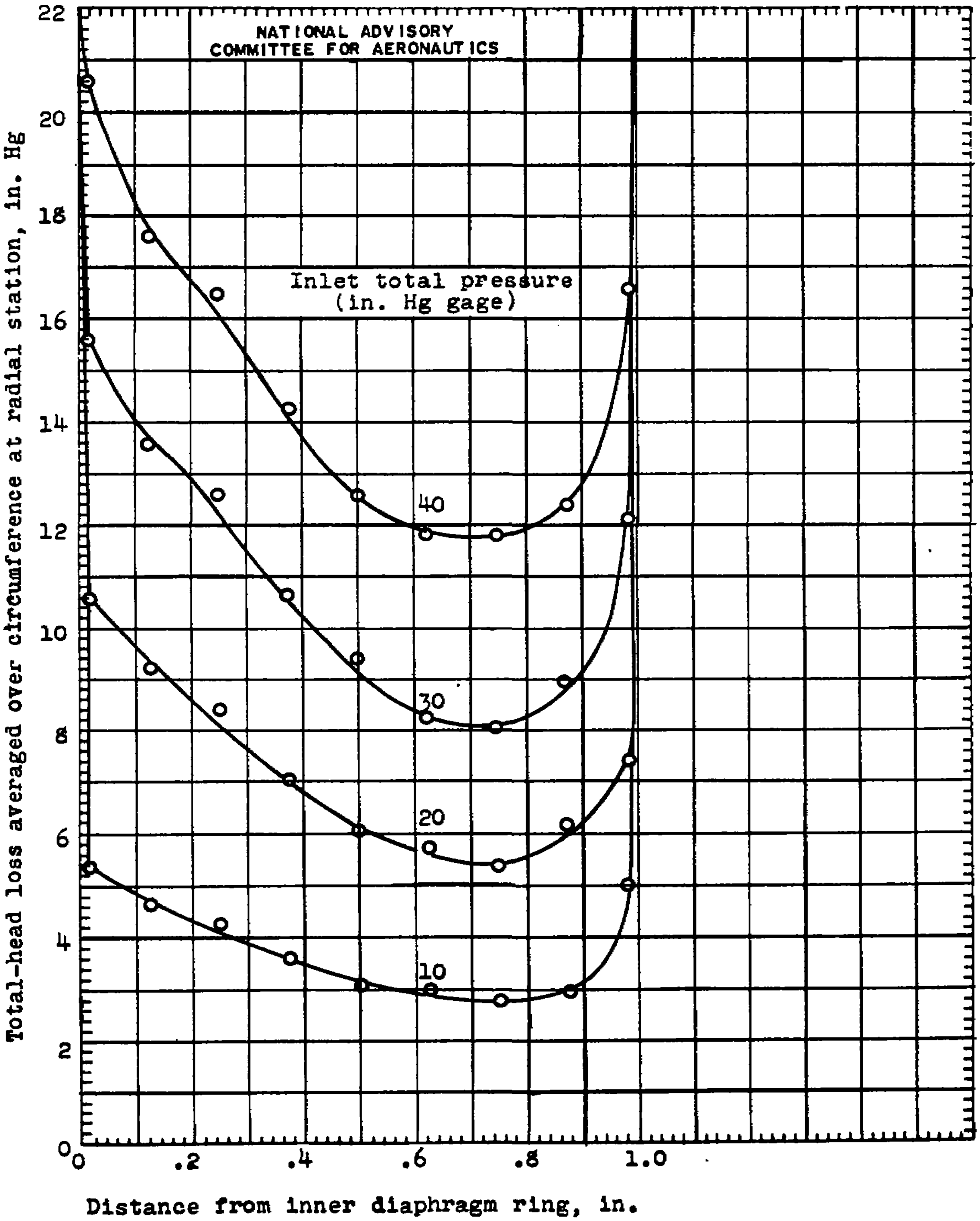


(d) Nozzle box D.

Figure 7. - Concluded. Mean total-head loss of each nozzle at pitch line.



(a) Nozzle box A.

Figure 8. - Radial distribution of mean total-head loss.

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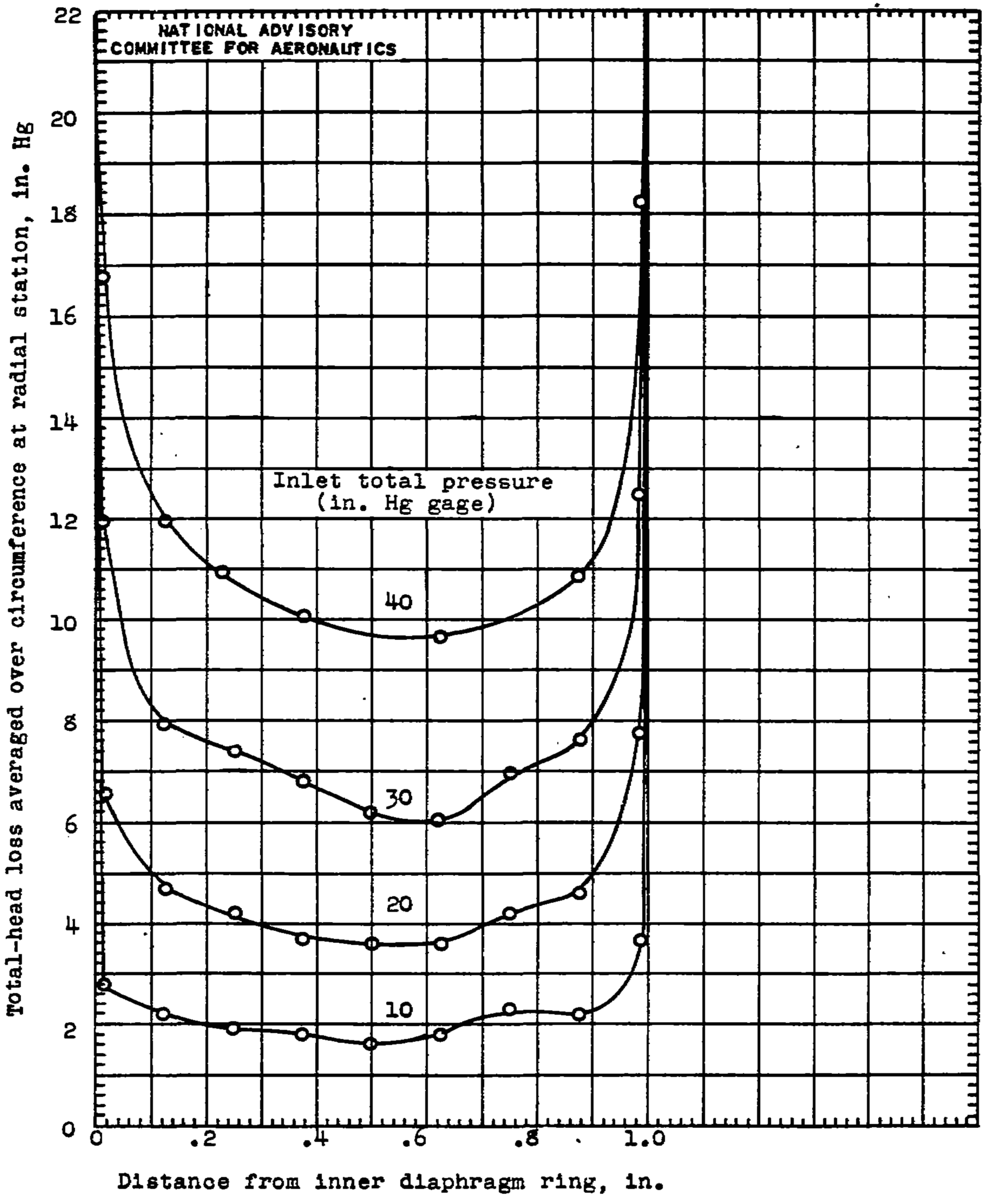
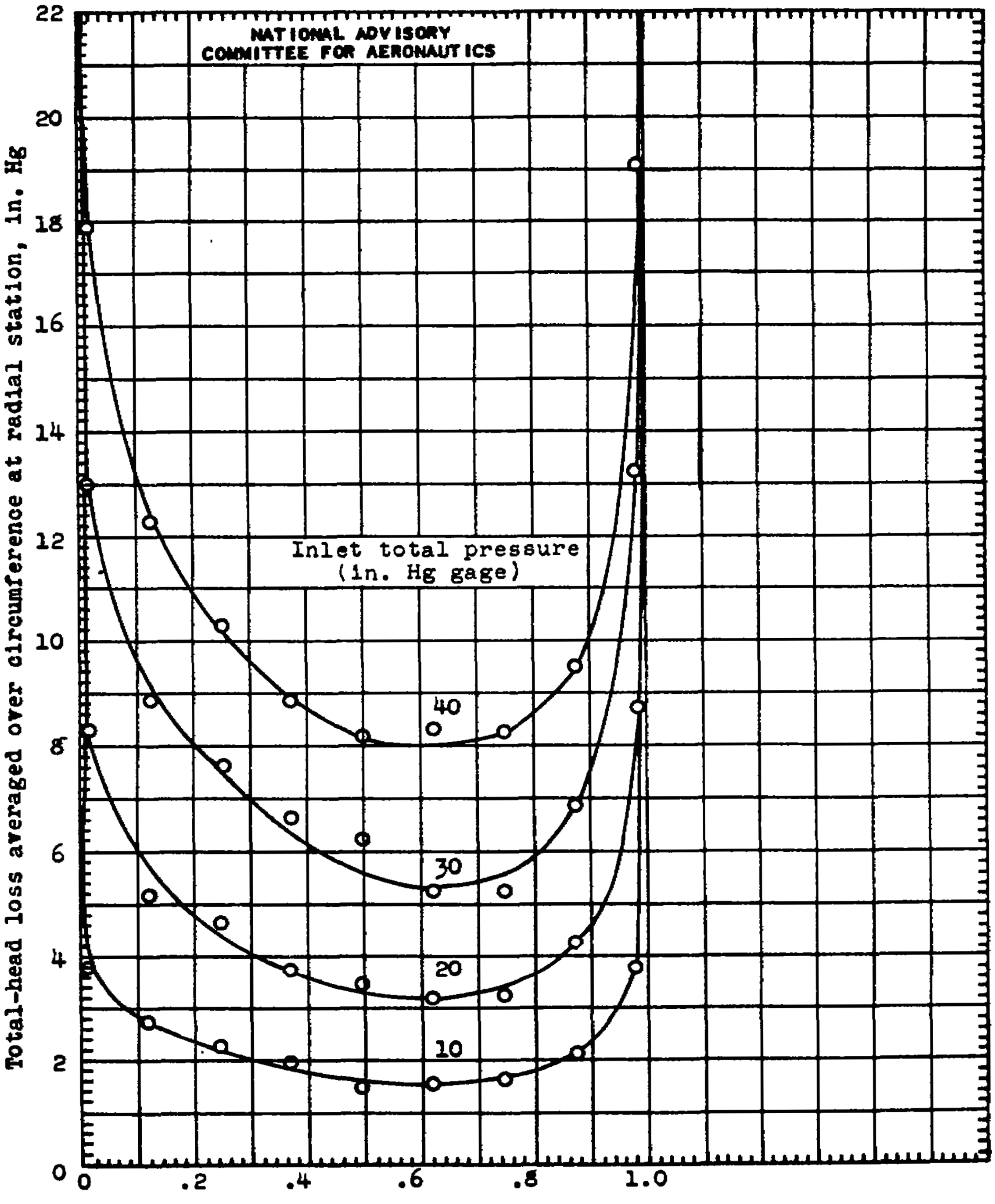


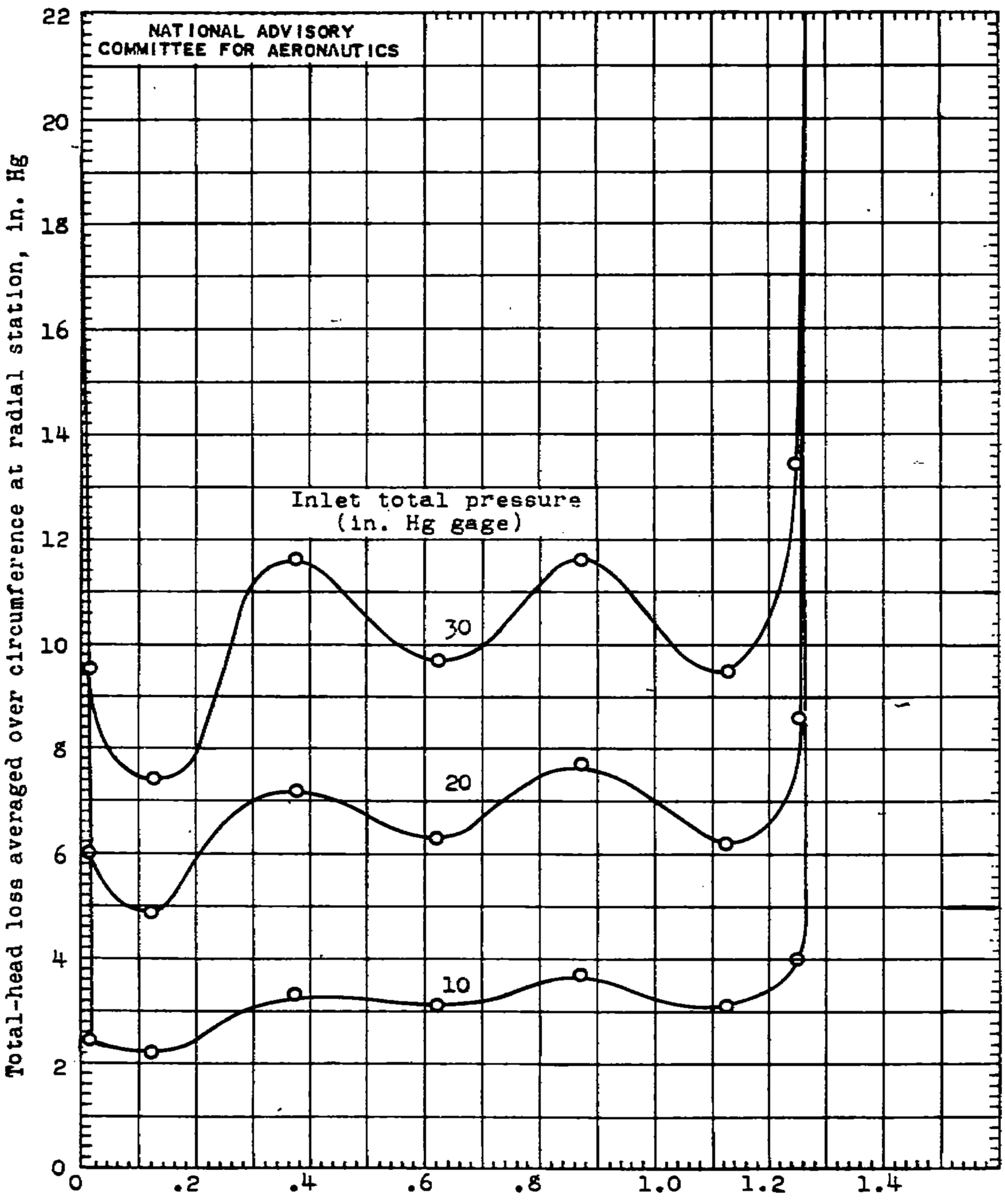
(b) Nozzle box B.

Figure 8. - Continued. Radial distribution of mean total-head loss.



(c) Nozzle box C.

Figure 8. - Continued. Radial distribution of mean total-head loss.



(d) Nozzle box D.

Figure 8. - Concluded. Radial distribution of mean total-head loss.

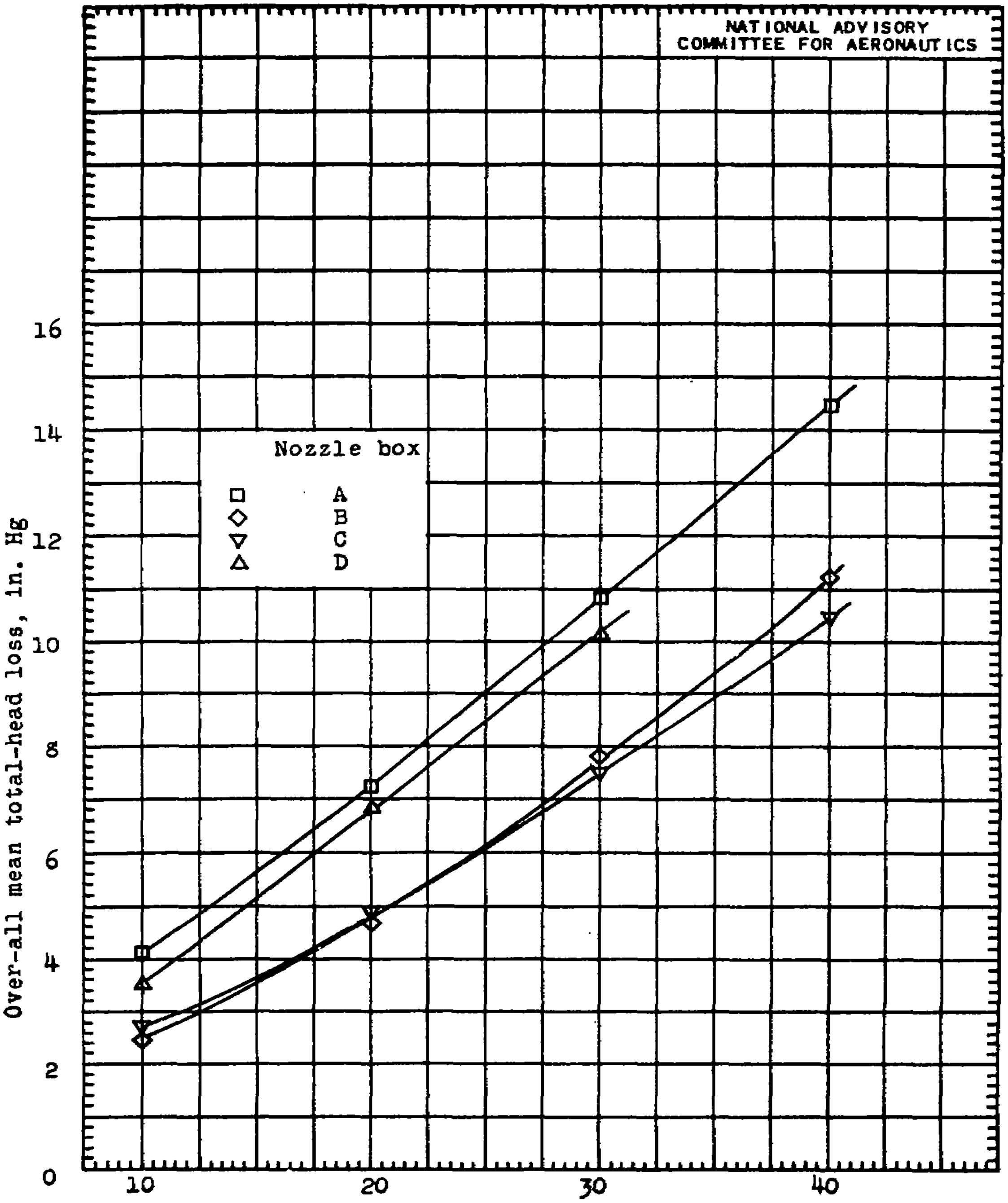


Figure 9. - Over-all mean total-head loss for various inlet pressures.